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ROTHERMEL'S FIRE SPREAD MODEL PROGRAMED FOR THE HEWLETT-PACKARD 9820

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ABSTRACT

A computer program assembled for the Hewlett-Packard 9800/ Model 20 is presented for calculating the rate of fire spread according to Rothermel's fire spread model.

OXFORD: 431.6:432:436. KEYWORDS: Fire behavior, fire control, fire use, computer program, Hewlett-Packard 9820, moisture of extinction, fire spread model, fire management.

INTRODUCTION

I have programed Rothermel's[1] fire spread model for the Hewlett Packard series 9800/Model 20 programable calculator. This calculator quickly solves Rothermel's set of parametric equations for obtaining the rate of spread through a porous fuel array.

This program was written for two fuel categories with up to nine size classes within each category. Detailed data inputs given by Rothermel[1] include moisture of extinction (see Appendix) for each category and the following fuel properties for each size class within a category:

1. Load--(lb./ft.^{2})
2. Heat content (low heat value)------------------------------------(B.t.u./lb.)
3. Fractional moisture content--------------------------------------(lb./lb.)
4. Surface area-to-volume ratio-------------------------------------(ft.$^{-1}$)
5. Total fractional mineral content---------------------------------(lb./lb.)
6. Particle density---(lb./ft.^{3})
7. Silica-free ash content (fractional)-----------------------------(lb./lb.)

---

[1]Richard C. Rothermel. A mathematical model for predicting fire spread in wild-land fuels. USDA For. Serv. Res. Pap. INT-115, 40 p., illus. 1972.

PROGRAM OPERATION

The fuel bed depth (ft.) must be entered following the fuel descriptors. An option is available in the program to weight the calculation of the reaction intensity in each category by the effective heating number, which in turn is evaluated from the characteristic surface area-to-volume ratio of the category.[2]

Finally, the slope and windspeed at midflame height (ft./min.) are requested by the programed calculator. The program is broken into two parts because of its large size. After obtaining the rate of spread, the second part of the program can be reinitiated for another rate-of-spread calculation with the same fuel descriptors and a different fuel depth, windspeed, and slope.

The program evaluates the following:

Reaction intensity--(B.t.u./ft.^{2}-min.)
Packing ratio---(ft.^{3}/ft.^{3})
Bulk density--(lb./ft.^{3})
Rate of spread--(ft./min.)

Interim results can be obtained by assessing the memory register (see Appendix, Register Printout).

The following program employs the math ROM in block 3; blocks 1 and 2 are empty. Internal registers total 429.

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[2]William H. Frandsen. Weighting the reaction intensity by the effective heating number. Intermt. For. & Range Exp. Stn., USDA For. Serv. Gen. Tech. Rep. (In prep.).

Step	Display	Part I Instructions
1		ERASE LOAD EXECUTE Alternately insert magnetic cards of Part I following the alphabetical sequence and EXECUTE until NOTE 14 is no longer displayed indicating completion of loading.
2		If input data are to be entered by magnetic cards insert after completion of the program cards and EXECUTE until NOTE 14 is no longer displayed.
3		END RUN PROGRAM
4	0-MANLOD 1-INREG	0 RUN PROGRAM if data are to be entered manually through the keyboard 1 RUN PROGRAM if data was entered from magnetic cards
5-1	NEXT MAG CARDS	Option 1 leads directly to the end of Part I indicated by flashing display (10X) followed by automatic initiation of load execution. Calculator is now ready for insertion of Part II. Go to Part II. Option 0 begins manual entry.
5-0	CLASSES CAT 1=?	m RUN PROGRAM m = classes in first category. $m \neq 0$
6	CLASSES CAT 2=?	n RUN PROGRAM n = classes in second category. n = 0 if there is only one category.
7	MEXT 1=?	p RUN PROGRAM p = moisture of extinction for category 1.
8	MEXT 2=?	q RUN PROGRAM q = moisture of extinction for category 2. ignored if n=0 in step 6.
9	LOAD = ?	a_i RUN PROGRAM a_i = load (lb./ft.^{2}) in class sequence i where i is sequential numbering of classes beginning with category 1 through category 2; i.e., if there are three classes in both category 1 and category 2 then i = 4 for the first class of category 2. Sequence number flashes between displays.

Step	Display	Part I Instructions
10	HEAT CONT=?	b_i RUN PROGRAM b_i = heat content (B.t.u./lb.) in sequence class i.
11	FRAC MOIS = ?	c_i RUN PROGRAM c_i = fractional moisture content in sequence class i.
12	SA/V = ?	d_i RUN PROGRAM d_i = surface area-to-volume ratio (ft.$^{-1}$) in sequence class i.
13	MNRL CONT = ?	e_i RUN PROGRAM e_i = total fractional mineral content in sequence class i.
14	PART DENS = ?	f_i RUN PROGRAM f_i = density of fuel particle (lb./ft.^{3}) in sequence class i.
15	SFA = ?	q_i RUN PROGRAM q_i = silica free ash content in sequence class i. Steps 9-15 repeated until i = m + n.
16	NEXT MAG CARDS	Flashing display (10X) followed by automatic initiation of load execution. Calculator is now ready for insertion of Part II.

Step	Display	Part II Instructions
1-A		Alternately insert program magnetic cards of Part II following the alphabetical sequence and EXECUTE until NOTE 14 is no longer displayed indicating completion of loading. Go to Step 2.
1-B		If Part II is the beginning and Part I did not precede Part II in operation (see later discussion), then ERASE LOAD EXECUTE. Follow instructions under Step 1-A above and go to Step 1-C.
1-C		Insert magnetic data card and EXECUTE until NOTE 14 is no longer displayed.
2		END RUN PROGRAM
3	FUEL DEPTH=?	d RUN PROGRAM d = Depth of fuel bed (ft).
4	WT BY EFF HTNG?	Option to weight by effective heating number. RUN PROGRAM
5	0-YES 1-NO	Option 0, 0 RUN PROGRAM The program will calculate the characteristic effective heating number, ε_i, of category i using the characteristic surface area-to-volume ratio of category i, replacing f_i, the weight factor, for category i.[1/] Option 1, 1 RUN PROGRAM Calculation proceeds as described by Rothermel using f_i, the surface area weighting factor.
6	WIND = ?	w RUN PROGRAM w = windspeed at midflame height (ft./min.).
7	SLOPE = ?	s RUN PROGRAM s = slope ($\Delta y/\Delta x$).

If there is only one class in one category, changes in fuel parameters can be achieved by directly accessing the appropriate memory register. However, if more than one class or category is required and changes are to be made in any of the following three parameters: load, surface area-to-volume ratio, and particle density, then it is necessary to begin again with Part I. One needs only to enter changes. For all other input requests, press Run Program.

APPENDIX

Recording Data

EXECUTE THE FOLLOWING:

REC "DA", R(8(R1+R2)+20)

EXECUTE

Register Printout

THE FOLLOWING PROGRAM LISTS ALL REGISTERS UP TO AND INCLUDING REGISTER R7+16.

```
0:
0→A;7(R1+R2)+37→
B⊢
1:
FXD 0;PRT A;FXD
4;PRT RA;A+1→A;
IF A≤B;JMP 0⊢
2:
SPC 8⊢
3:
END ⊢
R422
```

Register Identification

REGISTERS	QUANTITY
Ø	Ø - Manual load, 1 - data entered by magnetic card
1	Number of classes in category 1
2	Number of classes in category 2
3	Characteristic SA/V of category 1 (SA/V = Particle surface area-to-volume ratio)
4	Characteristic SA/V of category 2
5	Characteristic SA/V of entire fuel bed
6	Unused
7	7(R1+R2)+21
8	f_1, weighting parameter for category 1
9	f_2, weighting parameter for category 2
10	Fuel depth
11	Corrected organic load of category 1
12	Corrected organic load of category 2
13	Weighted heat content of category 1
14	Weighted heat content of category 2
15	Mineral damping coefficient of category 1
16	Mineral damping coefficient of category 2
17	Moisture damping coefficient of category 1
18	Moisture damping coefficient of category 2
19	Moisture of extinction of category 1
20	Moisture of extinction of category 2

REGISTERS	QUANTITY	
21,28...	Load--------------------------------------(i,j)	
22,29...	Heat content------------------------------(i,j)	
23,30...	Fractional moisture content---------------(i,j)	
24,31...	SA/V--------------------------------------(i,j)	
25,32...	Total fractional mineral content----------(i,j)	
26,33...	Particle density--------------------------(i,j)	
27,34...	Silica-free ash content-------------------(i,j)	
↓	j = 1 (category 1) i goes from 1 to R1 j = 2 (category 2) i goes from 1 to R2	
R7-1	= 7(R1+R2)+20 last of input data list	
R7	Weighting parameters	f(1,1) ↓ f(1,R1) f(2,1) ↓
8(R1+R2)+20		f(2,R2)
R7+10	β/β_{op}	β_{op} = optimum packing ratio
R7+11	Wind	
R7+12	Slope	
R7+13	I_R	= reaction intensity (B.t.u./ft.^{2}-min.)
R7+14	I_p	= propagating flux (B.t.u./ft.^{2}-min.)
R7+15	β	= packing ratio
R7+16	ρ_b	= bulk density (lb./ft.^{3})

Program Listing

FIRE SPREAD MODEL

Part I

```
0:
ENT "0-MANLOD 1-
INREG",R0;IF R0=
1;GTO "STRT"⊢
1:
ENT "CLASSES CAT
1=?",R1,"CLASSES
 CAT2=?",R2⊢
2:
0→A;ENT "MEXT 1=
?",R19;IF R2>0;
ENT "MEXT 2=?",R
20;GSB "1"⊢
3:
ENT "LOAD=?",R(A
7+21);GSB "1"⊢
4:
ENT "HEAT CONT=?
",R(A7+22);GSB "
1"⊢
5:
ENT "FRAC MOIS=?
",R(A7+23);GSB "
1"⊢
6:
ENT "SA/V=?",R(A
7+24);GSB "1"⊢
7:
ENT "MNRL CONT=?
",R(A7+25);GSB "
1"⊢
8:
ENT "PART DENS=?
",R(A7+26);GSB "
1"⊢
9:
ENT "SFA=?",R(A7
+27)⊢
10:
GTO +2⊢
11:
"1";A+1→B;FXD 0;
DSP B;DSP B;DSP
B;DSP B;DSP B;
RET ⊢
12:
IF R1+R2=B;GTO +
2⊢
13:
B→A;GTO 3⊢
14:
"STRT";0→A⊢
15:
7(R1+R2)+21→R7⊢
16:
R(A7+21)R(A7+24)
/R(A7+26)→R(R7+A
)⊢
17:
A+1→A;IF R1+R2>A
;GTO -1⊢
18:
0→A→B→C⊢
19:
IF R1>A;B+R(R7+A
)→B;A+1→A;JMP 0⊢
20:
IF R2>0;IF R1+R2
>A;C+R(R7+A)→C;A
+1→A;JMP 0⊢
21:
0→A⊢
22:
IF R1>A;R(R7+A)/
B→R(R7+A);A+1→A;
JMP 0⊢
23:
IF R2>0;IF R1+R2
>A;R(R7+A)/C→R(R
7+A);A+1→A;JMP 0
⊢
24:
B/(B+C)→R8;IF R2
>0;C/(B+C)→R9⊢
25:
0→A→B→C⊢
26:
IF R1>A;B+R(R7+A
)R(A7+21)/(1+R(A
7+25))→B⊢
27:
IF R1>A;A+1→A;
GTO -1⊢
28:
IF R2>0;IF R1+R2
>A;C+R(R7+A)R(A7
+21)/(1+R(A7+25)
)→C⊢
29:
IF R2>0;IF R1+R2
>A;A+1→A;GTO -1⊢
30:
B→R11;C→R12⊢
31:
0→A⊢
32:
DSP "NEXT MAG CA
RDS";A+1→A;IF A≤
10;JMP 0⊢
33:
END ;LOD ⊢
R308
```

FIRE SPREAD MODEL

Part II

```
0:
0→A→B→C⊢
1:
IF R1>A;B+R(R7+A
)R(A7+22)→B;A+1→
A;JMP 0⊢
2:
IF R2>0;IF R1+R2
>A;C+R(R7+A)R(A7
+22)→C;A+1→A;
JMP 0⊢
3:
B→R13;C→R14⊢
4:
0→A→B→C⊢
5:
IF R1>A;B+R(R7+A
)R(A7+27)→B;A+1→
A;JMP 0⊢
6:
IF R2>0;IF R1+R2
>A;C+R(R7+A)R(A7
+27)→C;A+1→A;
JMP 0⊢
7:
.174B↑(-.19)→R15
;IF R2>0;.174C↑(
-.19)→R16⊢
8:
0→A→B→C⊢
9:
IF R1>A;B+R(R7+A
)R(A7+23)→B;A+1→
A;JMP 0⊢
10:
IF R2>0;IF R1+R2
>A;C+R(R7+A)R(A7
+23)→C;A+1→A;
JMP 0⊢
11:
B/R19→Z;GSB "MD"
⊢
12:
Z→R17⊢
13:
IF R2>0;C/R20→Z;
GSB "MD"⊢
14:
Z→R18;GTO +3⊢
15:
"MD";IF Z≤1;1-2.
59Z+5.11Z↑2-3.52
Z↑3→Z;RET ⊢
```

```
16:
0→Z;RET ⊦
17:
0→A→B→C⊦
18:
IF R1>A;B+R(R7+A
)R(A7+24)→B;A+1→
A;JMP 0⊦
19:
IF R2>0;IF R1+R2
>A;C+R(R7+A)R(A7
+24)→C;A+1→A;
JMP 0⊦
20:
B→R3;C→R4;R8R3+R
9R4→R5⊦
21:
ENT "FUEL DEPTH=
?",R10;FXD 3;
SPC 2;PRT "FUEL
DEPTH=",R10;0→A→
B⊦
22:
IF R1+R2>A;B+R(A
7+21)/R(A7+26)→B
;A+1→A;JMP 0⊦
23:
B/R10→B;3.348R5↑
(-.8189)→X;B/X→X
;B→R(R7+15)⊦
24:
1/(4.774R5↑.1-7.
27)→A;R5↑1.5/(49
5+.0594R5↑1.5)→C
⊦
25:
CX↑AEXP (A(1-X))
→C;X→R(R7+10)⊦
26:
ENT "WT BY EFF H
TNG?",A,"0-YES 1
-NO",A⊦
27:
IF A=1;R8→X;R9→Y
;GTO +2⊦
28:
EXP (-138/R3)→X;
IF R2>0;EXP (-13
8/R4)→Y⊦
29:
CXR11R13R15R17→X
;CYR12R14R16R18→
Y⊦
30:
SPC 2;FXD 6;PRT
"RCTN INT-1=",X;
IF R2>0;PRT "RCT
N INT-2=",Y⊦
31:
X+Y→Y→R(R7+13);
PRT "TOT RCTN IN
T=",Y⊦
32:
YEXP ((.792+.681
R5↑.5)(B+.1))/(1
92+.2595R5)→R(R7
+14)⊦
33:
ENT "WIND=?",R(R
7+11),"SLOPE=?",
R(R7+12);SPC 2⊦
34:
PRT "WIND=",R(R7
+11),"SLOPE=",R(
R7+12)⊦
35:
7.47EXP (-.133R5
↑.55)→C;.02526R5
↑.54→B⊦
36:
.715EXP (-3.59E-
4R5)→A⊦
37:
5.275R(R7+15)↑(-
.3)R(R7+12)↑2→Y⊦
38:
CR(R7+11)↑BR(R7+
10)↑(-A)→X⊦
39:
R(R7+14)(1+X+Y)→
X;0→A→Y⊦
40:
IF .9R(R7+13)≤R(
R7+11);SPC 1;
PRT ".9RCTN INT≤
WIND";0→A→Y⊦
41:
IF R1+R2>A;Y+R(7
A+21)→Y;A+1→A;
JMP 0⊦
42:
Y/R10→Y→R(R7+16)
;0→A→B→C⊦
43:
IF R1>A;GSB "QG"
⊦
44:
IF R1>A;B+R(R7+A
)Z→B;A+1→A;GTO -
1⊦
45:
IF R2>0;IF R1+R2
>A;GSB "QG"⊦
46:
IF R2>0;IF R1+R2
>A;C+R(R7+A)Z→C;
A+1→A;GTO -1⊦
47:
Y(BR8+CR9)→Y;
GTO +2⊦
48:
"QG";EXP (-138/R
(A7+24))(250+111
6R(A7+23))→Z;
RET ⊦
49:
FXD 6;SPC 2;PRT
"PACKING RATIO="
,R(R7+15),"BULK
DENSITY=",R(R7+1
6)⊦
50:
SPC 2;FXD 3;PRT
"RATE OF SPREAD=
",X/Y⊦
51:
END ⊦
R203
```

Sample Register Printout

0	REGISTER # → ; MANUAL LOAD	0.0000
1	CLASSES IN CAT 1	4.0000
2	CLASSES IN CAT 2	4.0000
3	σ CAT 1	1248.0608
4	σ CAT 2	523.9885
5	$\tilde{\sigma}$	947.2496
6	—	0.0000
7	7(R1+R2)+21	77.0000
8	f_1	.5846
9	f_2	.4154
10	FUEL DEPTH	2.0000
11	$(\tilde{\omega}_n)_1$	.0157
12	$(\tilde{\omega}_n)_2$	.0363
13	$\tilde{h}_1$	8955.9138
14	$\tilde{h}_2$	8984.4032
15	$(\tilde{\eta}_s)_1$	.3501
16	$(\tilde{\eta}_s)_2$	.3664
17	$(\tilde{\eta}_m)_1$	.6503
18	$(\tilde{\eta}_m)_2$	.7886
19	$(M_{ext})_1$	3.1300
20	$(M_{ext})_2$	.2000
21	CAT 1 ↓; $(\bar{w}_o)_{ij}$ (cat, class)	.0078
22	$(\bar{h})_{ij}$	8966.0000
23	$i=1$, $j=1$; $(\bar{M}_f)_{ij}$	.7500
24	$(\bar{\sigma})_{ij}$	2000.0000
25	$(\bar{S}_T)_{ij}$	.0350
26	$(\bar{\rho}_p)_{ij}$	20.0000
27	$(\bar{S}_e)_{ij}$	.0350

28		.0256
29		8992.0000
30	$i=1$, $j=2$	.5500
31		487.0000
32		.0150
33		18.0000
34		.0150
35	$(\bar{w}_o)_{13}$	.0109
36	$(\bar{h})_{13}$	8327.0000
37	$(\bar{M}_f)_{13}$	.5500
38	$i=1$, $j=3$; $(\bar{\sigma})_{13}$	133.0000
39	$(\bar{S}_T)_{13}$	.0150
40	$(\bar{\rho}_p)_{13}$	31.0000
41	$(\bar{S}_e)_{13}$	.0150
42		.0043
43		8393.0000
44		.5500
45	$i=1$, $j=4$	67.0000
46		.0150
47		47.0000
48		.0150
49	CAT 2 ↓	.0002
50		8958.0000
51	$i=2$, $j=1$	.0200
52		2000.0000
53		.0150
54		20.0000
55		.0150

56		.0379
57		8992.0000
58	$i=2$, $j=2$	.0200
59		500.0000
60		.0150
61		18.0000
62		.0150
63		.0033
64		8327.0000
65		.0200
66	$i=2$, $j=3$	153.0000
67		.0150
68		46.0000
69		.0150
70		.0003
71		8393.0000
72	$i=2$, $j=4$	.0200
73		73.0000
74		.0150
75		51.0000
76		.0150

77	f_{11}	.5113
78	f_{12}	.4540
79	f_{13}	.0307
80	f_{14}	.0040
81	f_{21}	.0184
82	f_{22}	.9710
83	f_{23}	.0101
84	f_{24}	.0004
85		0.0000
86		0.0000
87	(β/β_{op})	.1819
88	WIND	176.0000
89	SLOPE	.4100
90	I_r	919.0200
91	I_p	19.3955
92	β	.0022
93	ρ_b	.0452

Sample Output

A sample output using the preceding sample register data is shown below.

```
FUEL DEPTH=
         2.000

RCTN INT-1=
     250.233431
RCTN INT-2=
     668.786576
TOT RCTN INT=
     919.020007

WIND=
     176.000000
SLOPE=
        .410000

PACKING RATIO=
        .002224
BULK DENSITY=
        .045150

RATE OF SPREAD=
        13.292
```

Moisture of Extinction

The following program (written for the HP 9820) will evaluate the moisture of extinction necessary as an input to the fire spread model.

Three inputs are requested: (1) dead fine fuel, (2) live fine fuel, and (3) dead moisture content. The first two are fuel loads and are entered in lb./ft.^{2}. The operator can decide which of the fine fuels are contributing to the desiccation of the live fine fuels and which of the live fuels are affected by the desiccation process. As a rule, the size classes considered to be fine fuels and used to calculate the moisture of extinction are: foliage, 0-inch to ¼-inch, and ¼-inch to ½-inch from the dead fuel; and foliage and 0-inch to ¼-inch from the live fuel. (Note that foliage is a separate class.) The dead moisture content is taken from the 0-inch to ¼-inch dead fuel size class. (Moisture contents of the dead fine fuel size classes should not differ greatly.) Outputs include the ratio of the live fine fuel load to the sum of both the live and dead fine fuel loads and the moisture of extinction.

```
0:
ENT "DEAD FINE F
UEL?",A,"LIVE FI
NE FUEL?",B⊢
1:
ENT "DEAD MOIS C
ONT?",C;PRT "DEA
D FINE FUEL=",A;
B/(A+B)→A⊢
2:
PRT "LIVE FINE F
UEL=",B,"DEAD MO
IS CONT=",C;SPC
1⊢
3:
PRT "LIVE TO TOT
AL","FINE FUEL R
ATIO=",A⊢
4:
2.9(1-A)(1-10C/3
)/A-.226→Z⊢
5:
SPC 1;PRT "EXTIN
CTION","MOISTURE
 CONT=",Z⊢
6:
END ⊢
R398
```

Sample Output

```
DEAD FINE FUEL=
             .03
LIVE FINE FUEL=
             .01
DEAD MOIS CONT=
             .13

LIVE TO TOTAL
FINE FUEL RATIO=
             .25

EXTINCTION
MOISTURE CONT=
            4.70
```


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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)